Process Integration
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Module - 4
Targeting
Lecture - 6
Shell Targeting- 1st Part

Welcome to the lecture series on Process Integration, this is module 4 lecture number 6, the topic of the lecture is number of Shell Targeting. Let us first try to know, while why shell targeting is required, we have already done number of units targeting, so why specially this shell targeting is require. Now, to know this, we should concentrate that, what type of heat exchangers are used in a heat exchanger network.

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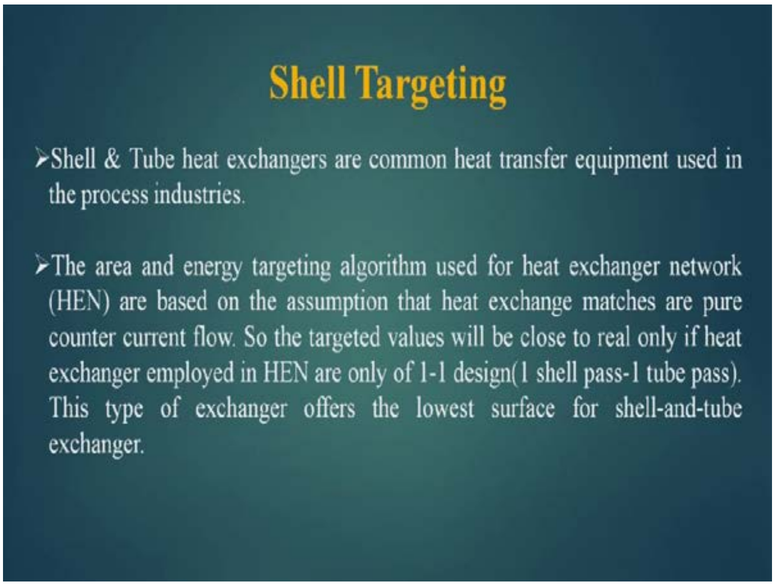

If we question this, we will find that, in most of the cases, shell and tube heat exchangers are common heat transfer equipment used in a process industry or in a HEN. The area and energy targeting algorithm used for heat exchanger network are based on the assumption that, heat exchange matches are pure counter current flow. So, the targeted values will be close to real one, only if heat exchanger employed in HEN are 1 1 that means, 1 shell pass and 1 tube pass design. If we use such type of heat exchangers in the HEN then, it will offer lowest surface for the heat exchanger network.

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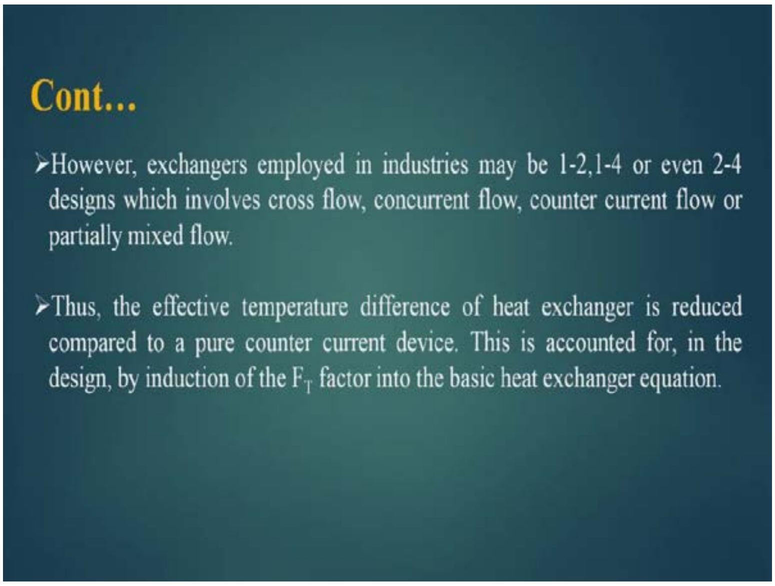

However, exchangers employed in industries are not 1 1 shell and tube heat exchangers, instead there may be 1 2 that means, 1 shell 2 tube pass, 1 4 that is 1 shell 4 tube pass and even 2 4 that is, 2 shell 4 tube pass heat exchanger designs, which involve cross flow, counter flow, concurrent flow and partial mixed flow. Thus, in such type of heat exchangers, the effective temperature difference of heat exchanger is reduced as compared to a pure counter current device. So, to account for this reduce in effective temperature difference, a factor F T is used in the basic heat exchanger design equation.

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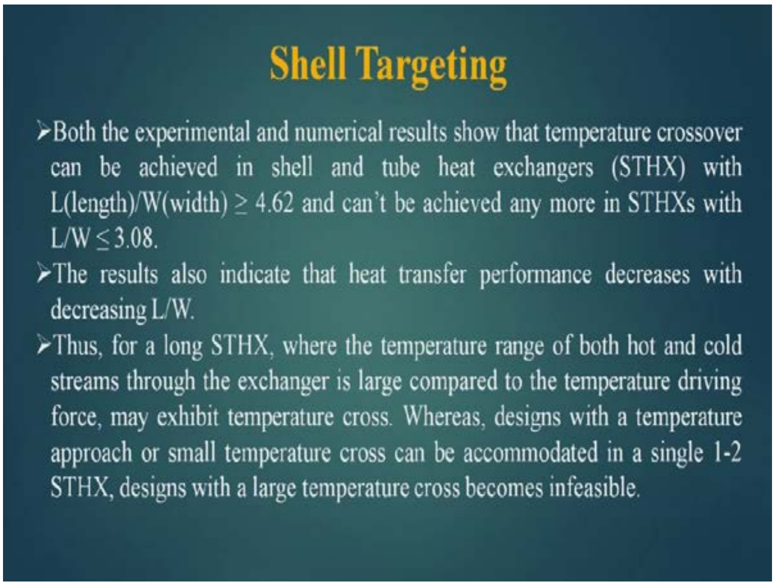

Further it has been seen, both through experimental and numerical computation that, the temperature crossover can be achieved in shell and tube heat exchangers with length to width ratio greater than 4.62 and cannot achieved anymore in shell and tube heat exchangers with length by width ratio less than 3.08. The results also indicate that, heat transfer performance decreases with increasing L by W ratio that is, length to width ratio. Further it should be noted that, the optimum heat exchangers are those heat exchangers, whose L by W ratios are high.

Thus, for a long shell and tube heat exchangers, while the temperature range of both hot and cold streams through the exchanger is large compared to the temperature driving force, this may exhibit temperature cross. Whereas, design through with a temperature approach or small temperature cross, can be accommodate in a single 1 2 shell and tube heat exchanger, whereas, the design with large temperature cross becomes infeasible.

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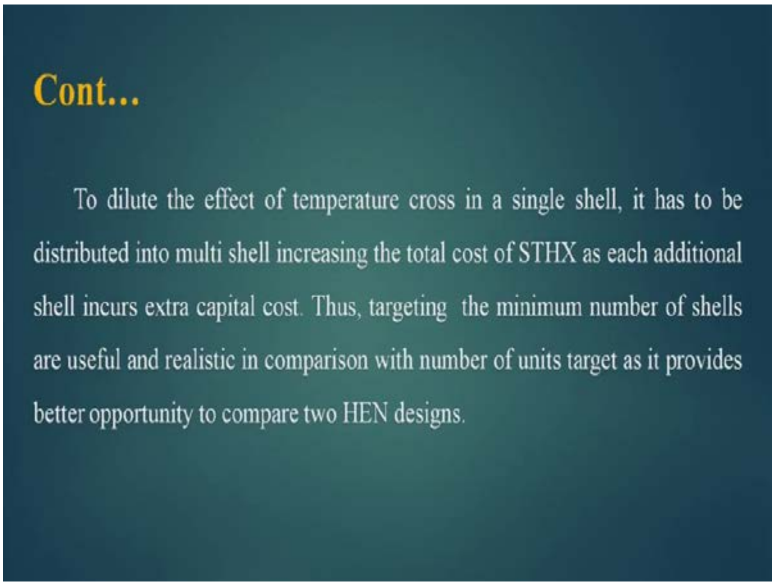

To accommodate the effect of temperature cross or to nullify the effect of temperature cross in a single shell and tube heat exchanger, it has to be distributed into multishell, increasing the total cost of shell and tube heat exchanger. Meaning, that if there is a temperature cross, considerable amount of temperature cross then, the design tells that, we should go for multishell heat exchangers to accommodate this. And if we go for a multishell heat exchanger then, the cost of the shell and tube heat exchanger increases considerably.

Thus, targeting the minimum number of shells are useful and realistic in comparison with number of units target, as it provides better opportunity to compare two HEN designs. Let us try to understand, what is a F T factor, which is a LMTD log mean temperature difference correction factor.

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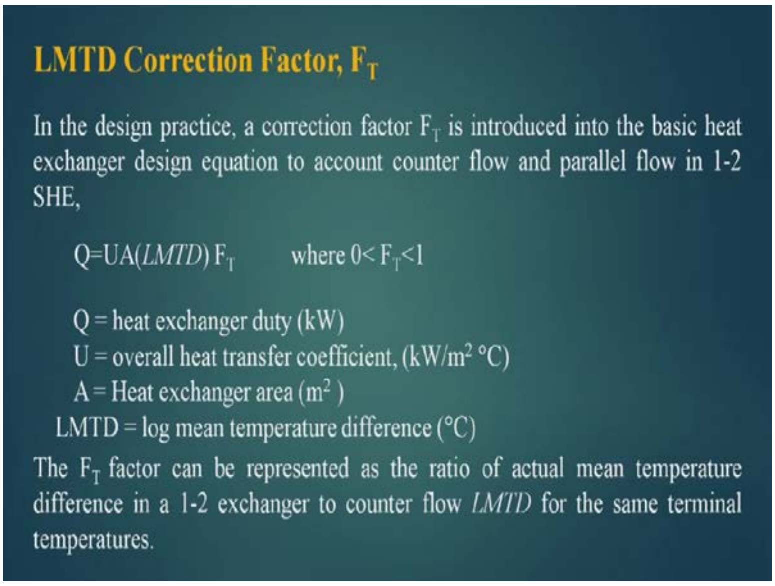

In the design practice, a correction factor F T is introduced into the basic heat exchanger design equation, to account for counter flow as well as parallel flow in 1 2 shell and tube heat exchangers. And the equation written is Q is equal to U A LMTD into F T, where the value of F T can vary from 0 to 1, where Q is the heat exchanger duty in kiloWatt, U is the overall heat transfer coefficient, A is the heat exchanger area and LMTD is the log mean temperature difference. The F T factor can be represented as the ratio of actual mean temperature difference in a 1 2 exchanger to counter flow LMTD for the same terminal temperatures.

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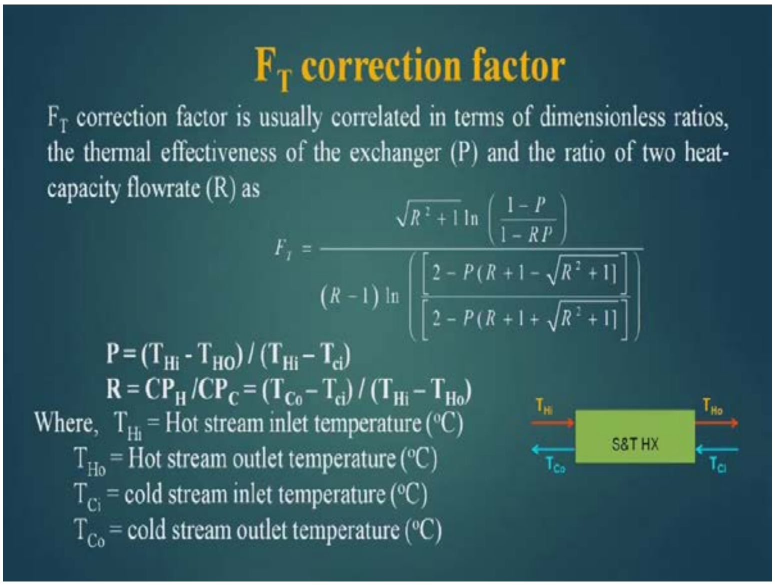

The F T correction factor is usually correlated in terms of two HEN factors, which are dimensionless in nature, the thermal effective of the heat exchanger called P and the ratio of two heat capacity flow rates called R. So, this shows the F T, the present slides shows the F T as a function of R and P, where P is equal to T Hi minus T Ho divided by T Hi minus T Ci.

And R is C PH minus C PC is equal to T Co minus T Ci divided by T Hi minus T Ho, where T Hi is the hot stream inlet temperature, T Ho hot stream outlet temperature, T Ci cold stream inlet temperature and T Co cold stream outlet temperature. Let us now try to understand, what is a temperature approach, and temperature cross.

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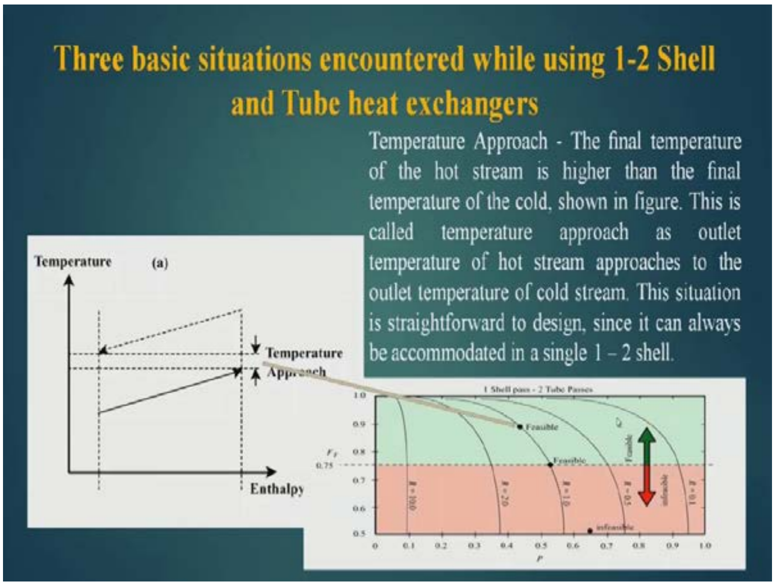

The figure clearly shows that, the hot stream, the inlet temperature is this and the outlet temperature is this. Whereas, the cold stream inlet temperature is this and outlet temperature is this, this axis shows the enthalpy, all length of the heat exchanger and this is the temperature axis. From here, we see that, the outlet temperature of the hot stream is little bit more than the outlet temperature of the cold stream, so there is a gap and this gap is called temperature approach.

Now, if it is the case and we want to correlate a heat exchanger with some temperature approach then, this design falls in the upper part of this F T versus P graph, where R is a parameter, so it is a feasible design and here the F T is around 0.9. So, in this plot, the red portion shows infeasible design and the green portion shows feasible design.

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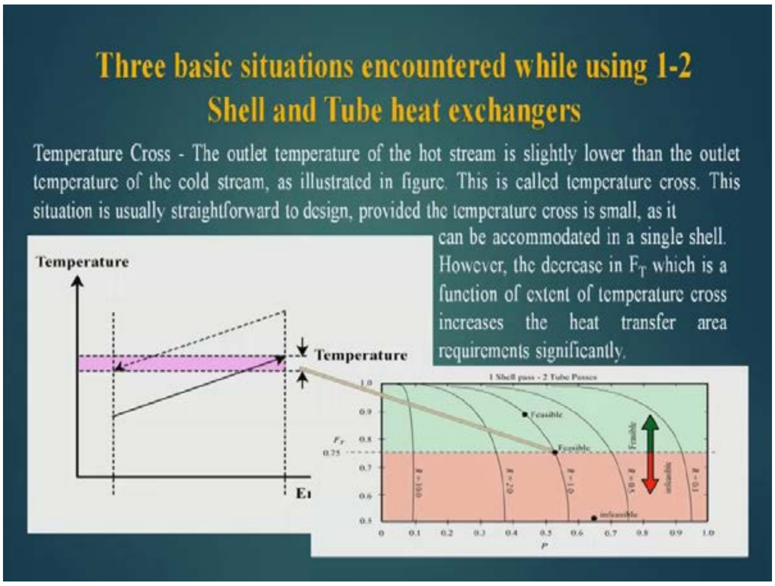

Plus see the same graph, but where here the outlet temperature of the hot is below the outlet temperature of the cold. So, there is consider amount of temperature cross here, though the temperature cross is not very high. The outlet temperature of the hot stream is slightly lower than the outlet temperature of the cold stream, this is called temperature cross. This situation is usually straight forward to design, provided the temperature cross is small, as it can be accommodate in a single shell.

However, it decreases the F T value of the heat exchanger that means, it will require significantly higher amount of area. So, if I want to map this type of heat exchanger into the F T P diagram then, this exchanger can be given by this point, which is very close to infeasible region. This line which separates the feasible and infeasible region, the value of F T is 0.75 that means, if I compute the value of F T to be 0.75 then, it is almost in the border line case of feasible and infeasible design.

If the F T is lower than the 0.75 then, it is not advisable to design the heat exchanger with a single shell and some design modification has to be done to increase this F T value. And the general design modification is to increase the number of shells to improve the F T factor.

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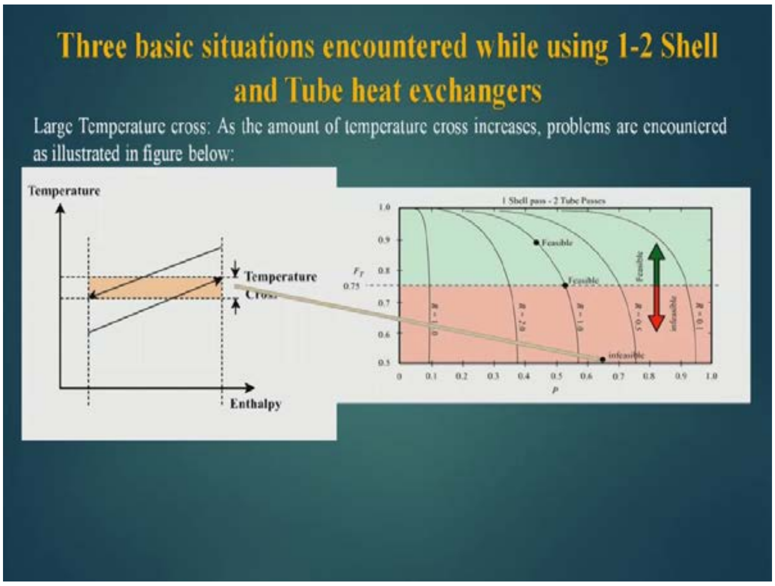

A third type of situation will occur when there is a large temperature cross, now if I map this type of heat exchangers, where there is large temperature cross. Then, this will map into the infeasible region of the F T versus P curve and here, the value of F T will be far low than 0.75. In such a situation, either the heat exchanger is not design or multishell heat exchanger has to be design to improve the F T till improve the F T factor is more than 0.75. Infeasible exchanger design returns F T, very low value of a F T or F T less than 0.

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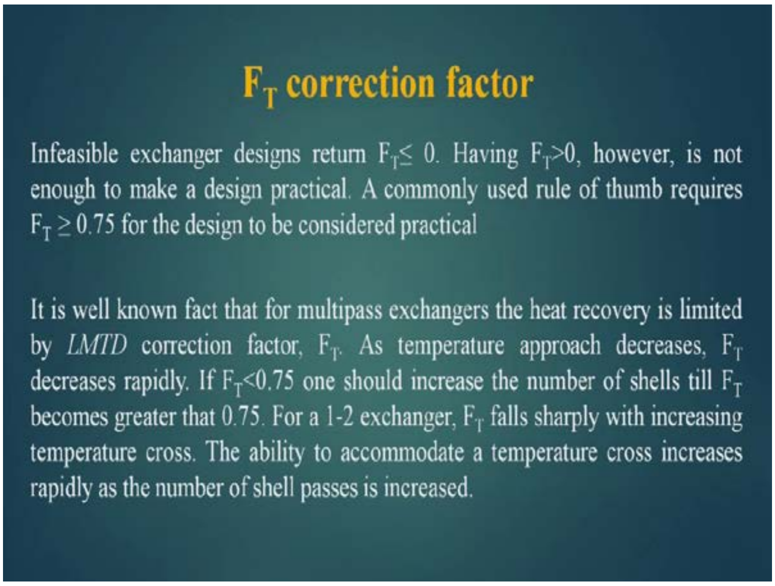

Having F T greater than 0, however is not enough to make a design practical, a commonly used rule of thumb requires F T greater than 0.75, for the design to be considered practical. It is well known fact that, for multi pass heat exchangers, the heat recovery is limited by LMTD correction factor F T, as temperature approach decreases, F T decreases rapidly. If F T is less than 0.75, one should increase the number of shells till F T becomes greater than 0.75.

For a 1 2 exchanger, if F T falls sharply with increasing temperature cross, the ability to accommodate a temperature cross increases rapidly as the number of shell pass is increased. Meaning, that if the F T is less than 0.5, the designer has to obtain multiple shell heat exchanger or the number of shell should be increase such that, F T becomes more than 0.75, now this gives the basis for shell targeting.

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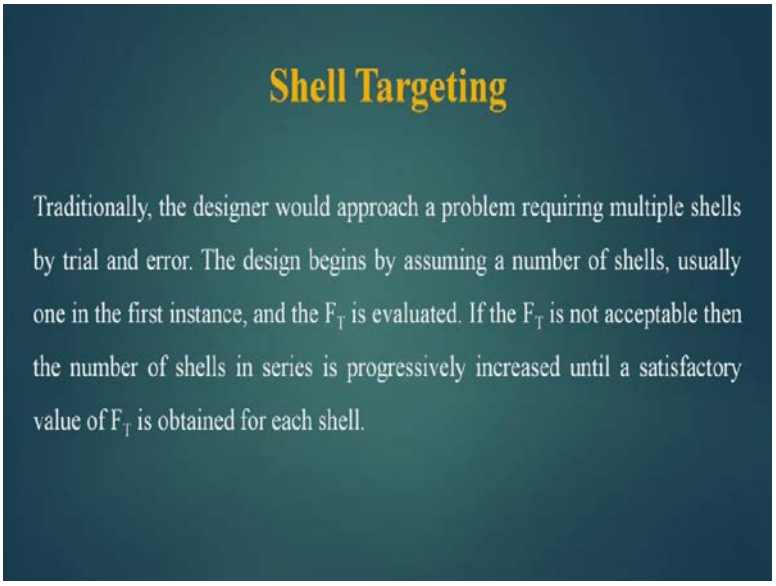

Traditionally, the designer would approach a problem requiring multiple shells by trial and error, till the F T factor becomes more than 0.75. The design begins by assuming a number of shells, usually one in the first instance and the F T is evaluated. If the F T is not acceptable then, the number of shells in series is progressively increased until a satisfactory value of F T is obtained for each shell.

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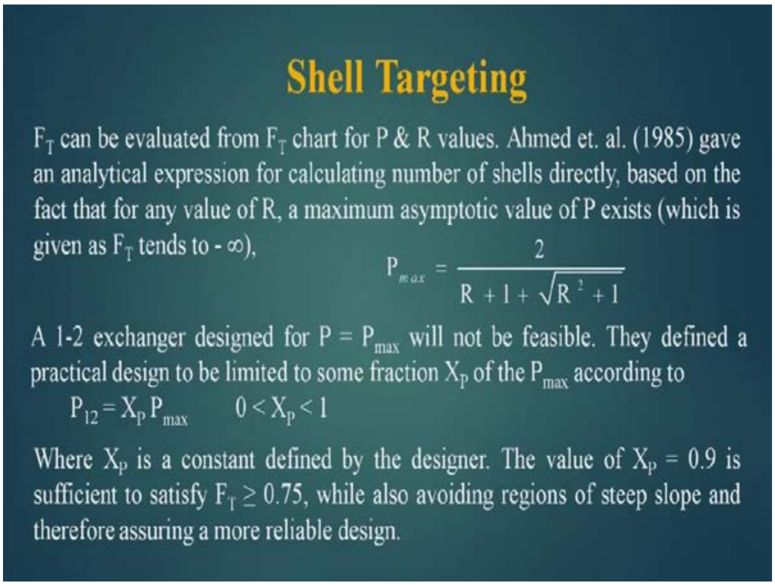

Now, have been known that, why multiple shells are necessary in the design and with the increase in the shells, the cost of the heat exchanger increases. That is why, if we compare the number of units target with the service number of shell targeting then, we find that, the number of shell is targeting is far accurate than number of units targeting and this gives us a method to evaluate the HENs. That means, if there are two HENs, HEN 1 and HEN 2 then, HEN 1 has got 8 shells and HEN 2 has got 10 shells.

Probably, we would like to take the HEN 1, because it has got less shells and hence, it is fixed cost will be less than the HEN 2. Now, let us find out, how to proceed for shell targeting, F T can be evaluated from F T charts and P R values. If P and R values are known, we can find out F T from F T charts. Ahmed et. al. in 1985 given analytical expression for calculating number of shells directly based on the fact that, for any value of R, a maximum asymptotic value of P exists, which gives F T value, which tends to minus infinite.

So, p X, p maximum is equal to 2 divided by R plus 1 plus root over R square plus 1, a 1 2 exchanger design for P equal P max will not be feasible. Because, at this point, P max point, F T will tends to minus infinite and we generally do not design if F T falls below 0.75. They define the practical design to be limited to some fraction of X P of the P max, the fraction is X P and a practical design will occur when I multiply P max with a fraction X P, while the value of X P can be 0 to 1. It has been seen that, if the X P value is equal to 0.9, it is sufficient to satisfy a design, where F T is greater or equal to 0.7, while also avoiding regions of steep slope and therefore, assuring a more reliable design.

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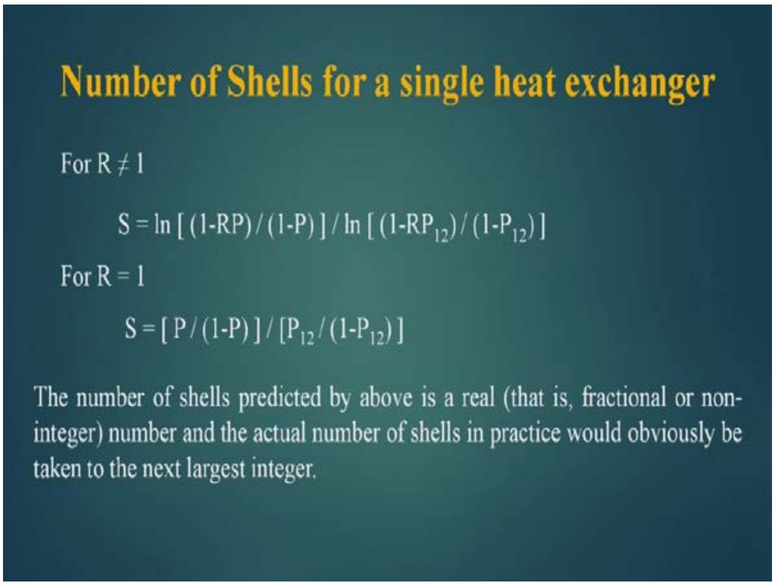

Now, based on this, we can have two equations to find out the number of shells, for R is not equal to 1, S is equal to log 1 minus R P divided by 1 minus P then, whole divided by ln, in brackets 1 minus R P 12 R into P 12 brackets closed, divided by in bracket 1 minus P 12, where P 12 is or P 1 2 is equal to X P into P max. For R equal to 1, the number of shells R P divided by, in brackets 1 minus P whole divided P 1 2 divided by in brackets 1 minus P 1 2 then, whole bracket closed.

The number of shell predicted by above equation is a real quantity that means, it is a fractional non integer quantity. And thus, when we predict shells, it would be obviously to taken into the next largest integer value. Now, the question is, how to calculate number of shells for HEN before the design. As I had already told that, all targets are achieved before the design, so this is a exclusively a very good technique, a pinch technology, where before the design the targets are fixed.

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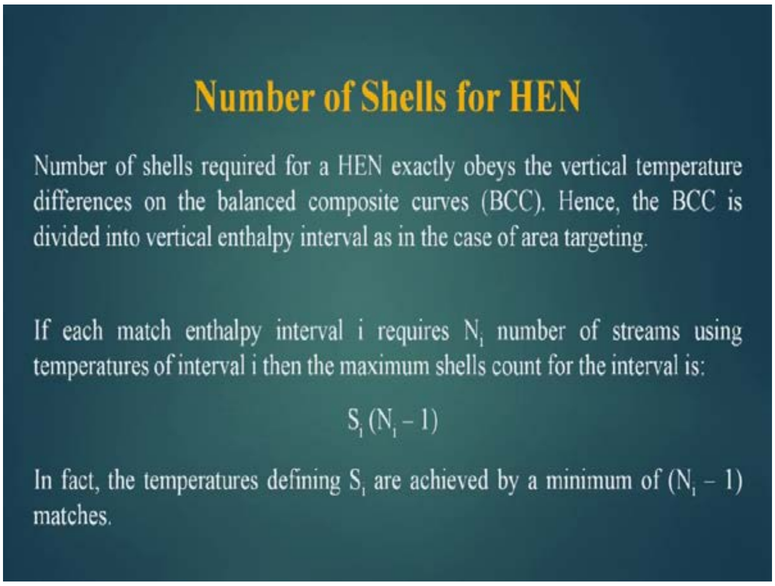

To calculate the number of shells in the HEN, the composite curves that is, hot and cold composite curves are divided into a number of enthalpy interval and here also, we obvious the vertical temperature difference. Now, for this purpose, we create a balanced composite curve, which is called BCC, we have see until now, the composite curves, the hot and cold composite curves. When in a hot and cold composite curves, the hot utilities as well as cold utilities are plotted then, it converts into a balanced composite curve.

Because, in such stage, the heat available with the hot utility plus the hot streams is exactly equal to the heat required for the cold streams and cold utility and that is why, such a plot is called balanced composite curve. And then, this balance composite curve, BCC is divided into vertical enthalpy intervals, as in the case of area targeting. In the area targeting, we have take taken it and a details of constructing a BCC is given. If each match enthalpy interval i requires N i number of streams using temperatures of interval i then, the maximums shells for the interval is S i into N i minus 1.

The foundation of this equation is from units target, we know that the number of units is equal to the number of streams in a particular interval minus 1. So, once number of streams is known and I know that, in each number streams, there is a certain amount of shells. Then, when this is multiplied with number of units, I get total number of shells in that enthalpy interval, which is given by S i into N i minus 1, N i minus 1 gives you the number of units and S i gives that how, what is the number of shells per number of unit.

In fact, temperature defining S i are achieved by the minimum of N minus 1 matches, the real or the non integer number of shells target is then simply the sum of the real number of shells from all the enthalpy intervals.

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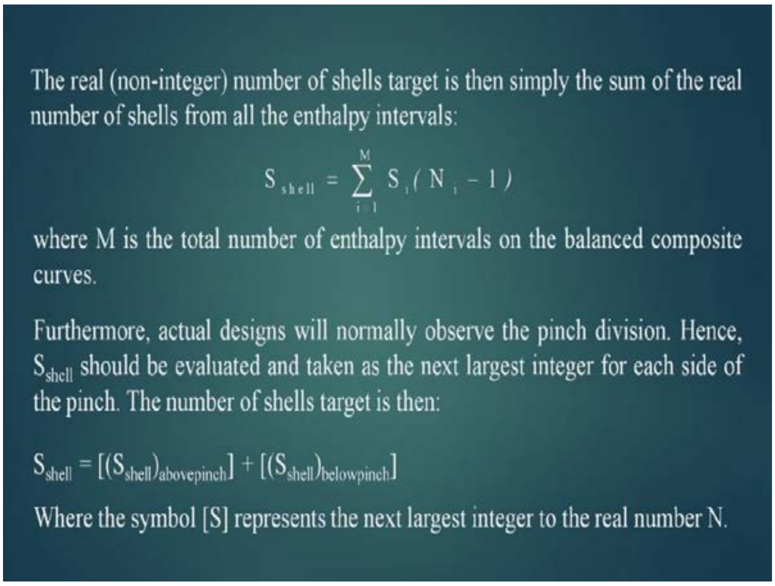

Suppose, I have M number of enthalpy intervals then, in the each interval, I will find out what is the value of number of shells and then, I will multiply this with the number of streams including hot, cold utilities minus 1 in that interval. So, it will give me the number of shells in that enthalpy interval and then, while I will sum up this for M intervals, that will give me the number of shells in the whole BCC curve. Furthermore, actual design will normally observe the pinch division.

If I go for a MER design, have a pinch division, it has been told that, through pinch no heat flows, when I go for a maximum energy recovery design. And hence, pinch point divides the whole problem into two different parts, one is called above pinch and the another is called below pinch. As they are thermally balanced, so for a pinch design, we have to find out number of shells above the pinch and then, we have to find out number of shells below the pinch.

Then, for each number has to be converted into a whole number and then, when we add it up then, we find out, what is the total number of shells in that design. To see that how the shells targeting is done, we will show this through an example.

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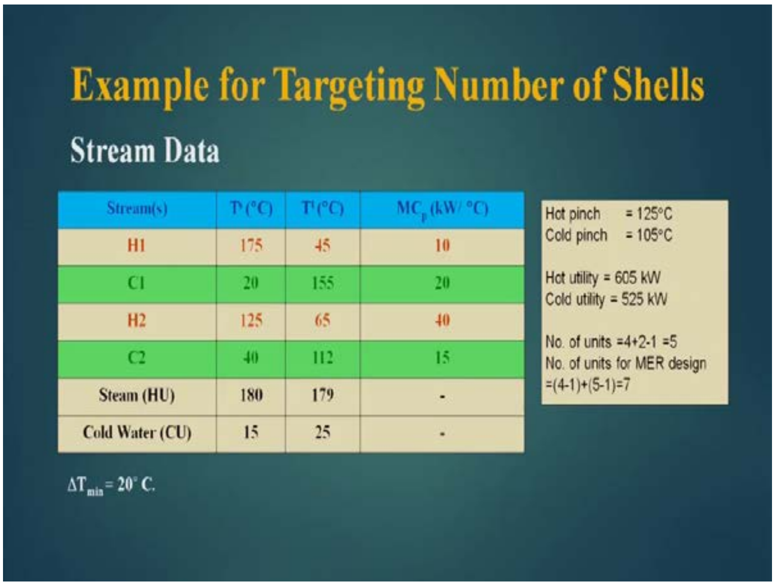

Here, we see a steam data table, which has two hot streams and two cold streams, one hot utilities steam and another cold utility, which is cold water. So in fact, we have 6 streams here, whose supply and target temperature are given and M C P values are given. Now, if we plot this or we do the PTA of this stream data then, we find that hot pinch is at 125 degree Centigrade and cold pinch is at 105 degree Centigrade and this is for delta T minimum equal to 20 degree Centigrade and the hot utility demand is 605 kiloWatt and the cold utility demand is 525 kiloWatt.

If I find out the number of units, the total number of units, define the pinch division then, it is 4 streams, hot and cold stream plus 2 utilities streams minus 1 is 5. So, if I ignore pinch division then, 5 number of units can do the heat exchange that means, the heat exchanger network will required only 5 number of heat exchangers. And if I go for MER design, that means pinch division, I consider the pinch division then, in the upper there are 4 streams including the utility, 4 minus 1 and the lower part, there are 5 stream including utility, so 5 minus 1, so this is 3 plus 4 is equal to 7 units.

So, in the MER design, the number of units target gives 7 units if I consider the pinch division and number of units target gives 5 units if I do not consider the pinch division. So, this will remember and will compare with the shells target data.

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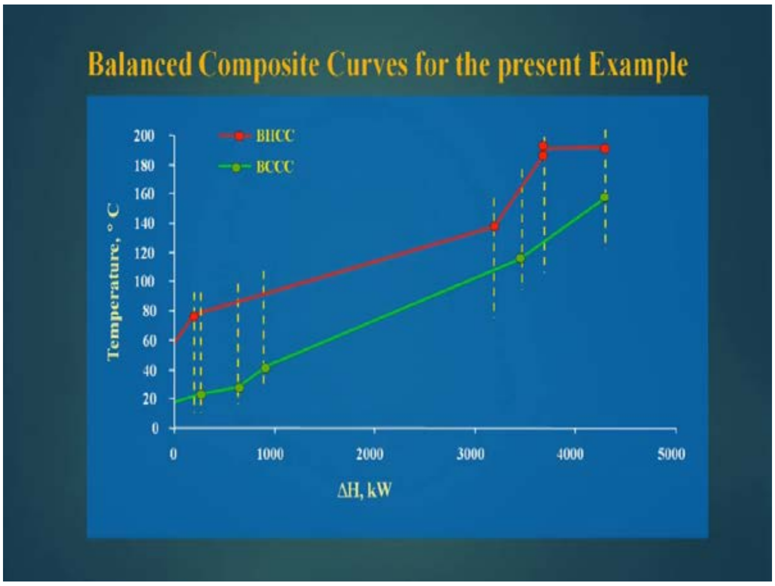

Now, this shows a balanced composite curve, because here we have use the cold utility and here, we have use the hot utility. And the total heat available with the hot stream as well as hot utility is given to the cold stream with cold utility and that is why, it is called a balanced composite curve. Now, here we have divided it, where there is a slope change, from that point we have divided this into many enthalpy intervals, this is 1 2 3 4 5 like this.

Now, here we see that, this temperature is known to us, but ((Refer Time: 30:45)) this temperature is not known to us. This temperature is known to us, but this temperature is not known to us, this temperature is known to us, but this temperature is not known to us, this temperature is known to us, this temperature is not known to us, this temperature is known to us, this is not known to us so on, so forth. So, our fast first job will be, to find out these unknown temperatures.

So, if I find out these unknown temperatures, so both end are known that means, this temperature is known, this temperature is known of the hot, this temperature is known and this temperature is known for the cold. So, this looks like a temperature profile of a counter current heat exchanger. And knowing this temperatures, I can find out the value of P and R and once P and R values are known, I can find out what will be the value of S i, because computation only needs P and R values and we have taken X P is equal to 0.09.

So, once I know the S i value for this enthalpy interval and if I know the number of cold stream and hot stream and including the cold utility then, I can find out, what will be the number of units here, using number of units target. And then, I can multiply this with the number of shells per unit and can find out the number of shells require for this enthalpy interval. Similarly, I will do for ((Refer Time: 32:40)) this enthalpy interval, this enthalpy interval, this enthalpy interval, this enthalpy interval, this enthalpy interval, this enthalpy interval, this enthalpy interval.

And then, I will add up all the shells and then, I will find out the total number of shells, which are required for this problem. Here also, we will see that, will divide this problem into two parts, above the pinch and below the pinch and we will add up the number of shells at the above the pinch and below the pinch. And then, we will convert them to integers and then, we will add up to find out the total number of shells for this problem.

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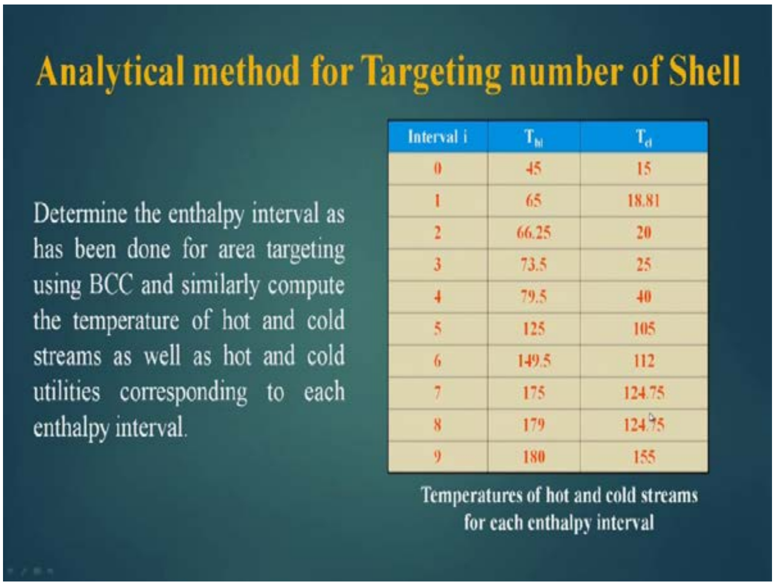

So, how to do this has been clearly demonstrated in area targeting, so I will request the readers to see the area targeting lecture and find out how for each intervals, the T hi and T ci have been computed. This requires a certain amount of efforts to do this and these are you done by intrapolation method. So, let us see the calculation procedure for P, I have told you that, for calculation of number of shells, we have to first calculate the value of P and R, this is required. And P values and R values can be computed through the values known that is, T hi and T ci.

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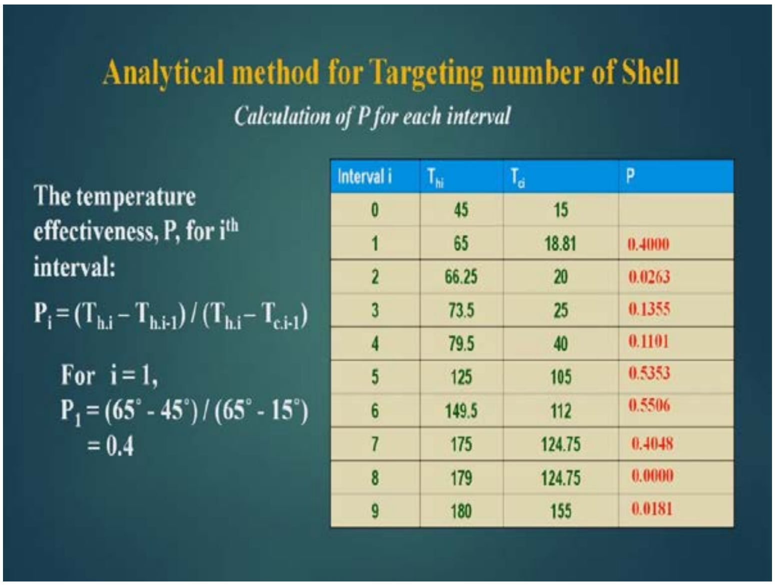

So, took we have 0 interval, 1 2 3 4 5 6 7 8 9 intervals, so to calculate P in the i th interval, so the formula is P i T hi minus T hi minus 1 divided T hi minus T si minus 1. So, for the first interval if I calculate, this is T hi is 65, T hi minus 1 is equal to 45, T hi is 65, T ci minus 1 is 15. So, for i equal to 1, this is the value and my P i is 0.4, so this 0.4 goes here. Similarly, I can calculate the P i values of other intervals that is, this enthalpy intervals and we can fill it up. So, we are able to calculate the P values for all the temperature intervals, which are enthalpy intervals in this case then, the next stage is to compute the R values.

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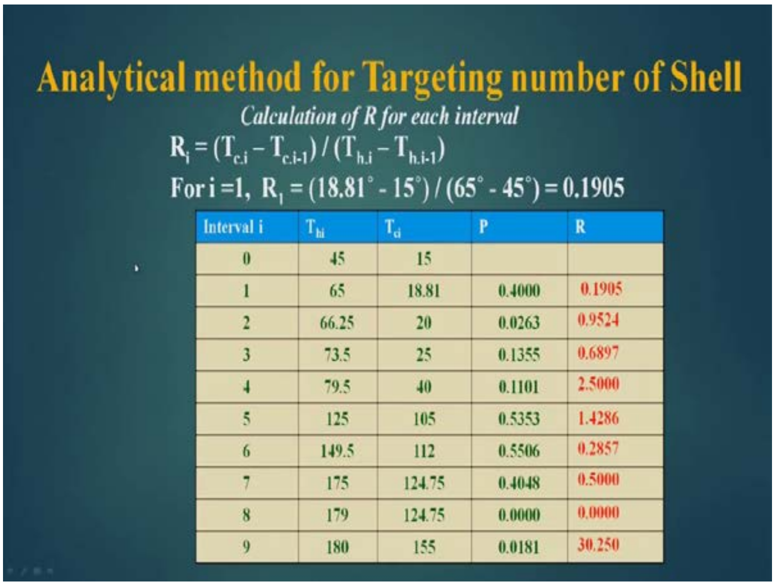

So, here the R value is equal to T ci minus T ci minus 1, T hi minus T hi minus 1, so for i equal to 1, will be using this four set of data here. So, here T ci for i equal to 1 is this value, 18.81 and T ci minus 1 is this value, which is 15. So, 18.81 minus 15 divided by T hi is this value, 65 and T hi minus 1 is this value, 45, so 65 minus 45, so it comes out to be 0.1905. So, for i equal to 1, we can fill this then, subsequently you can calculate for other enthalpy intervals and we can fill it up.

May be for this interval too, we will use this two data and ((Refer Time: 37:15)) this two data, and for this third interval, we will use this two data and this two data and fourth we will use this four data that means, fourth row or fourth row data and third row data. And for fifth, we will use fifth row data, this two data and this two data and so on and so forth for ninth, we will use this two data and this two data. in this manner we can find out the value of R. Now, once P and R are known, the next stage will be to find out, what will be the value of number of shells.

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Analytical method for Targeting number of Shell

Calculation of the temperature effectiveness of an individual 1-2 exchanger

$P_{12} = X_p P_{max}$ where $P_{max} = 2 / (R+1+(R^2+1)^{1/2})$ and $X_p = 0.9$

For i=1, $P_{12,i=1} = 0.9 *[2 / (0.1905+1+(0.1905^2+1)^{1/2})] = 0.815$

Interval i	T_{hi}	T_{ci}	P	R	P_{12}
0	45	15			
1	65	18.81	0.4000	0.1905	0.815
2	66.25	20	0.0263	0.9524	0.5400
3	73.5	25	0.1355	0.6897	0.6197
4	79.5	40	0.1101	2.5000	0.2907
5	125	105	0.5353	1.4286	0.4314
6	149.5	112	0.5506	0.2857	0.774
7	175	124.75	0.4048	0.5000	0.6875
8	179	124.75	0.0000	0.0000	0.0000
9	180	155	0.0181	30.250	0.0293

Now, here we are calculating P 1 2, this P 1 2 is nothing but, X P into P max, so P 1 2 is equal to X P into P max and the formula P max is this, 2 divided by R plus 1 root over R square plus 1, where X P value is 0.9. So, I have the value of R, so I can calculate P max, I know the value of X P, which is 0.9, so I can multiply the value of X P with P max and I can calculate the value of P 1 2.

So, if I do this for i equal to 1, this P 1 2 comes out to be 0.815, this uses the R value here that is, 0.105. And this is the value of X P, which we have used, this is 0.9 or I can fill up the P 1 2 values for all the enthalpy intervals starting from 1 to 9.

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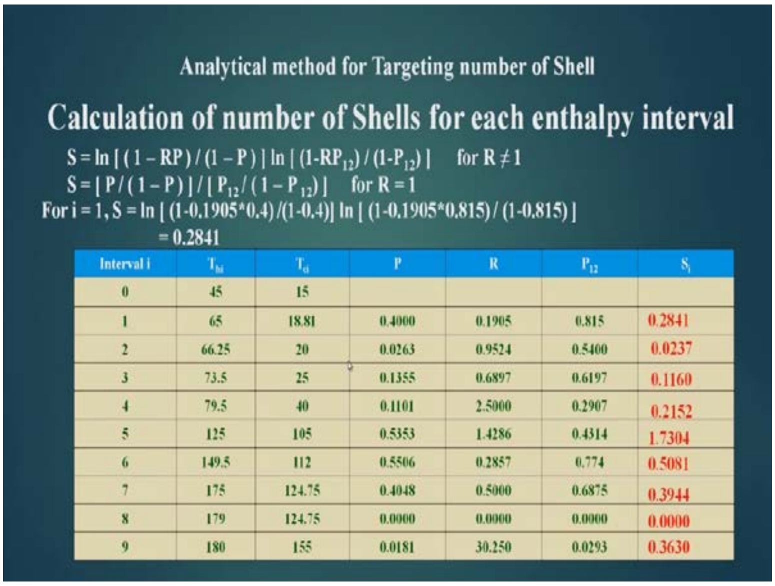

Once P R and P 1 2 is known, we can calculate the S values that is, number of shell values and the formula for this is given. And here we can see that, the S is a function of R, P and P 1 2 when R is not equal to 1. And when R is equal to 1, it is a function of P and P 1 2, because for R equal to 1, we can put the value of R as 1 and obviously, the functional relationship with R vanishes, because it becomes a constant. So, there are two equations are available, if R is equal to 1 and when R is not equal to 1.

So, we can see here then, none of the intervals R is equal to 1, so we will use this formula, which tells to calculate, which gives us the method to calculate the value of S when R is not equal to 1. When S will be calculate for an interval, this will be called S i, so for i equal to 1, we can use these three quantities to compute the S i value. Here, this is 1 minus R, R value is 0.1905 into 0.4, this is the value of P, this is 0.4, this is 0.4 then, 1 minus P, 1 minus the value of P 0.4 bracket close and we are going for logarithm of this whole value and then, logarithmic of this value.

So, we get a computed value as 0.2841, so this is 0.2841, here basically there is a division line here, I think it is divided, here also this is divided, so this is 0.2841 and I can fill up the values here. So, once S i number is calculated then, I have to find out the value of N i minus 1 that means, for each enthalpy interval, we have to compute how many number of streams are there. And then, we have to find out N i minus 1 value and then, we multiply S i value to that. And for each interval, we will find out, what will be the value of number of shells, so for this purpose, we have to plot the stream population.

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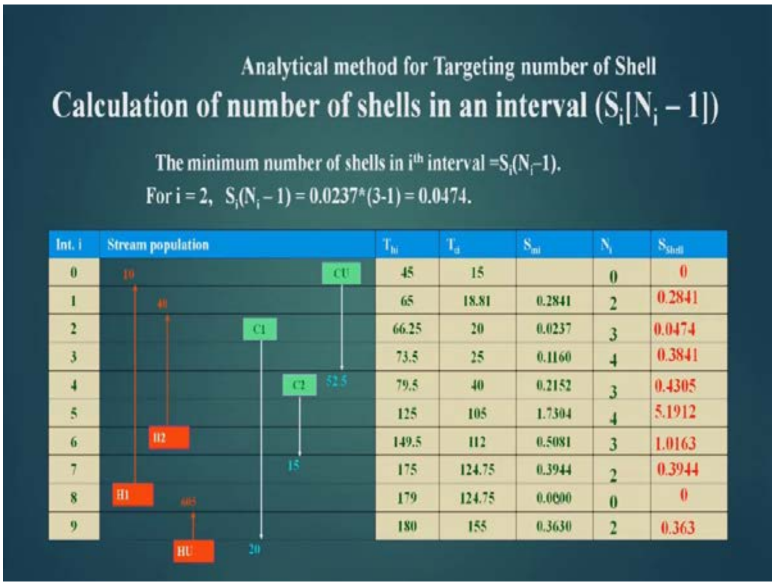

Here if I see, in interval number 1 I have only 2 streams operating, in the interval number 2 I have 3 streams operating, whereas in interval number 3 I have 1 2 3 4 streams are operating. So, from here, I can calculate what is the N i value in each interval and then, with N i minus 1 I can multiply this S i value, this is S i value and then, I can find out the S shells for each interval, so this is filled up. I can check for interval number 3, there are 1 2 3 4 streams are present, so N i is equal to 4.

And for interval 2, there are 1 2 3 streams present, so it is N i is equal to 3. So, for i equal to 2, S i N i minus 1 is, S i is 0.0237 into this is 3, so 3 minus 1, this is 0.474, so for this i equal to 2, the number of shells is 0.474. Similarly, for all other intervals, I can compute the value of shells, so we fill it up. So, here we find 0, because there is a temperature jump at this point and for we are joining two streams with a T Cs hot stream, which will not require any heat transfer. And hence, the number of shells for that part of T cs stream is 0, that is why this has come 0.

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Now, we have this table, that intervals are that T hi is that, T ci is that and number of shells are that, for each enthalpy interval. Now, we see that, this is not an integer value, so now, we have to find out, where is the pinch division and then, we will divide the problem into two parts, upper pinch are and lower pinch area. And then, we will count the number of shells and then, convert it into the next integer. And for the upper pinch section and lower pinch section, we will do this and then, we will add it them up to find out the number of shells.

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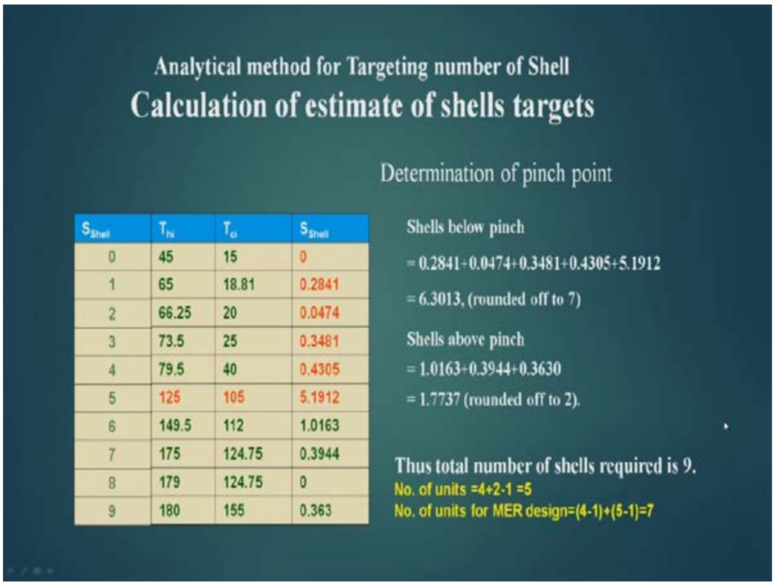

So, the pinch point is this, I have already told you that, the pinch of this problem is 125 the hot pinch, 105 is the cold pinch. And at this point interval, which is the fifth interval it falls, the number of shells is 5.1912. So now, we will compute the number of shells available above the pinch, so these are 0.2841 this close here, 0.0474, 0.3481, 0.4305, and 5.1912, when we add this, it becomes 6.3013 and if you round of it, it becomes 7. Now, shell above the pinch, we can calculate like that and it becomes to 2, so shells above pinch 2, shells below pinch 7 and then, when add those numbers, it becomes 9.

So, number of shells target gives of a value, that for this problem, number of shells will be 9. Now, if we compare this with the units target, if I ignore the pinch, the number of units target will be 5 and number of units for a MER design when I consider pinch, it will be 7. So, the number of shells target gives a better figure than number of units target and we are more close to the actual scenario, if we compare the shells target and units target, shell target gives you a better picture, which is more close to the real scenario. And hence, shells target is better than the units target and by knowing the shells target, we compare different HEN designs, which can be generated for a single problem utilizing the pinch rules.

Thank you.